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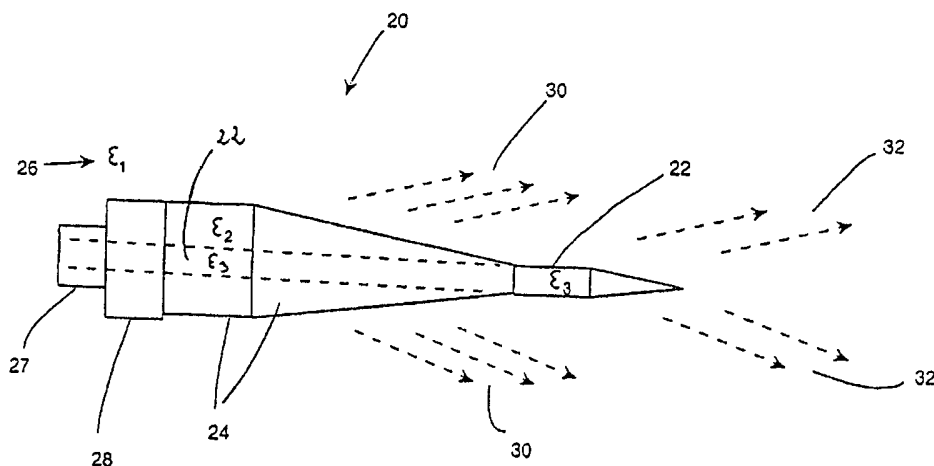
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(54) Title: DIELECTRIC ROD ANTENNA



(57) Abstract: An antenna. The antenna (20) includes a first dielectric antenna rod (22) having a first dielectric constant (23). The first dielectric antenna rod is coupled to a first frequency transmission source (27) for propagating first frequency band radiation from the first dielectric antenna rod into a medium having a medium dielectric constant (ϵ_1). A second dielectric antenna rod (24) is provided having a second dielectric constant (ϵ_2). The second dielectric antenna rod is coupled to a second frequency transmission source (28) for propagating second frequency band radiation from the second dielectric antenna rod into the medium. The first dielectric antenna rod is coaxially mounted within the second dielectric antenna rod. The first dielectric constant is greater than the second dielectric constant. The second dielectric constant is greater than the medium dielectric constant.



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

DIELECTRIC ROD ANTENNA

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a U.S. continuation-in-part application of U.S. Patent Application No. 09/879,865 (filed June 12, 2001), which is a U.S. continuation-in-part application of U.S. Patent Application No. 09/482,166 (filed January 12, 2000). U.S. Patent Application Nos. 09/879,865 and 09/482,166 are incorporated herein by this reference.

FIELD

- 5 This disclosure relates to the field of antennas, and more particularly, to antenna structures for covering a diversity of frequency bands. More specifically, this disclosure relates to a coaxial dielectric rod antenna with multi-frequency collinear apertures.

10 BACKGROUND

- A large number of different radio frequency systems have come into use for communication, navigation, electronic warfare and radar systems. State-of-the-art automotive and aerospace-borne vehicles which utilize such radio frequency systems
15 could have more than a dozen separate antennas to cover a diversity of frequency bands. However, many mobile platforms have limited space for multiple antennas operating in widely separated frequency bands.

- Alternatively, a number of wide bandwidth antenna elements have been developed
20 for electronic warfare and signal intelligence systems. Current state-of-the-art antennas include flared notch elements, each with about an octave of bandwidth (2:1). Other antenna elements such as spirals, log periodic elements, biconical dipoles and conical monopoles all have a bandwidth limit of about 2:1 and they tend to have relatively large physical dimensions and, as such, are not well-suited for mobile
25 platform vehicular use.

One solution to this multi-antenna, multi-aperture problem now faced by land, sea, air and space-borne vehicles has been multi-function, multi-frequency, phased array antenna apertures with electronic beam forming and scanning/tracking. However, today broadband antenna elements and phased array antennas are limited by the bandwidth and dimensions of the antenna feed elements to a maximum frequency ratio of about one octave (2:1). Broad bandwidth phased array antennas composed of broadband feed elements must address several conflicting design parameters:

- 1) low side lobes require that the phase centers of the feed antennas be closely spaced one half wavelength apart at the highest frequency of operation;
- 2) feed antennas have dimensions approaching one half wavelength at the lowest operating frequency;
- 3) large numbers of broadband amplifiers must be connected to every feed antenna in a 2:1 bandwidth array; and
- 4) a second set of crossed linear antenna elements and associated electronics often are required if the array is to transmit and receive signals in orthogonal linear polarization and in both circular polarizations.

Therefore, there exists a need for an effective antenna structure which can cover a diversity of frequency bands, a diversity of polarizations, and can be useful in phased array antenna systems. The present invention provides a unique solution to meet such needs.

SUMMARY

In accordance with the present invention, an inventive three dimensional, ultra-broad bandwidth, multi-aperture, dielectric antenna is provided which combines features of tapered dielectric rod antennas and coaxial dielectric waveguide transmission lines. The coaxial dielectric rod antenna (CDRA) in accordance with the present invention has multi-frequency collinear apertures which can be optimized for use as individual multi-band antennas or as feed elements in broad bandwidth active aperture phased array antennas. In essence, the CDRA in accordance with the present invention combines into a single structure many separate antennas which cover a diversity of frequency bands.

A first embodiment of the invention includes a first dielectric antenna rod having a first dielectric constant. The first dielectric antenna rod is coupled to a first frequency transmission source for propagating first frequency band radiation from the first dielectric antenna rod into a medium having a medium dielectric constant. A second dielectric antenna rod is provided having a second dielectric constant. The second dielectric antenna rod is coupled to a second frequency transmission source for propagating second frequency band radiation from the second dielectric antenna rod into the medium. The first dielectric antenna rod is coaxially mounted within the second dielectric antenna rod. The first dielectric constant is greater than the second dielectric constant. The second dielectric constant is greater than the medium dielectric constant.

In accordance with the first embodiment, the second dielectric antenna rod can include an axial cylindrical cavity along the length of the second dielectric antenna rod. The axial cylindrical cavity can be filled with a dielectric powder having the first dielectric constant. The dielectric powder can be secured within the axial cylindrical cavity by end plugs having the first dielectric constant and be located at respective

proximal and distal ends of the second dielectric antenna rod. Further, the first frequency transmission source can be axially coupled to the first dielectric antenna rod while the second frequency transmission source can be coupled to the second dielectric antenna by a transmission line axially offset from the second dielectric antenna rod. The second dielectric antenna rod can be made of a thermoplastic resin. The dielectric powder can be barium tetratitanate or nickel-aluminum titanate.

Another embodiment of the present invention includes a first dielectric antenna rod having a first dielectric constant. The first dielectric antenna rod is coupled to a first frequency transmission source for propagating first frequency band radiation from the first dielectric antenna rod into a medium having a medium dielectric constant. A second dielectric antenna rod is provided having a second dielectric constant. The second dielectric antenna rod is coupled to a second frequency transmission source for propagating second frequency band radiation from the second dielectric antenna rod into the medium. The first dielectric antenna rod is coaxially mounted within the second dielectric antenna rod. A third dielectric antenna rod having a third dielectric constant is also provided. The third dielectric antenna rod is coupled to a third frequency transmission source for propagating third frequency band radiation from the third dielectric antenna rod into the medium. The second dielectric antenna rod is coaxially mounted within the third dielectric antenna rod. The first dielectric constant is greater than the second dielectric constant. The second dielectric constant is greater than the third dielectric constant. The third dielectric constant is greater than the medium dielectric constant.

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BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows in schematic form a prior art polyrod tapered dielectric antenna.

Fig. 2 shows in schematic form an embodiment of the present invention.

Fig. 3 shows a partially exploded perspective view of an embodiment of the present invention.

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Figs. 4a - 4c show plan and section views of an embodiment of the present invention.

Fig. 5 shows in schematic form another embodiment of the present invention.

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Figs. 6a - 6c show alternative embodiments of the present invention.

DETAILED DESCRIPTION

15

A uniform rod of dielectric material is a well-known type transmission line for electromagnetic waves ranging in wavelength from radio to optical frequencies. Various microwave and milli-meter wave dielectric transmission lines have been demonstrated, including single dielectric fibers, as described in U.S. Patent 4, 20 293,833 issued to Popa, and coaxial fibers of multiple dielectrics as described in U.S. Patent 4,800,350 issued to Bridges et al. A microwave transition using dielectric waveguide is described in U.S. Patent 5,684,495 issued to Dyott et al. in which a dielectric rod antenna couples a standard metallic waveguide to a dielectric rod transmission line.

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Similarly, narrowband polyrod dielectric antennas and antenna arrays are well-known. Such antennas include those developed at the Bell Telephone Laboratories during World War II for radar antenna array elements, as described in the Bell System Technical Journal, Vol. XXVI, 1947, pages 837 - 851. Also, an

embedded dielectric rod antenna has been described in U.S. Patent 4,274, 097 issued to Krall et al. that embeds a dielectric rod antenna with a relative dielectric constant of 84 in a dielectric cylinder of relative dielectric constant 81. High dielectric constant material is used to form a compact narrow beam antenna.

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Further, dual frequency antennas have been developed involving a dielectric transmission line. A dual frequency feed satellite antenna horn is described in U.S. Patent 4,785,306 issued to Adams in which a Ku band dielectric transmission line passes along the center of a conventional metallic C-band waveguide and then exits
10 through an end wall.

In dielectric transmission lines of this type, a portion of the energy travels along the inside of the dielectric rod and a portion travels along in the space outside of the rod. Electromagnetic energy can propagate along the dielectric fiber in a series of
15 modes with the lowest order HE₁₁ mode being the mode of primary interest. The useful bandwidth of the dielectric waveguide extends from the lowest frequency at which the HE₁₁ mode is reasonably well contained up to the lowest frequency where the next lowest order modes, the TM₀₁ and TE₀₁, can propagate.

20 When internal or external discontinuities are encountered along the dielectric rod, radiation takes place. This tendency was used to advantage at the Bell Telephone Laboratories in the 1940s to form the microwave "polyrod" antennas. A representative polyrod tapered dielectric antenna 10 is schematically depicted in Fig. 1 and is discussed in more detail in Chapter 16 of the Antenna Engineering
25 Handbook, published by McGraw-Hill, 1961. Dielectric antenna 10 is coupled to metal waveguide 12 and typically has a feed taper 14, a body taper 16, a straight section 18 and a terminal taper section 20. In the dielectric rod antenna, radiation is encouraged from all parts of the rod by gradually tapering the diameter of the rod and then abruptly terminating it at a point where the radiation has been essentially

completed. By well-known proper design techniques, this radiating structure forms a directional endfire antenna with the gain determined primarily by the length of the taper.

- 5 The dielectric rod transmission line can be turned into a coaxial dielectric transmission line by surrounding the core rod with a second dielectric cylinder of lower dielectric constant. This outer sheath confines the electric fields less tightly than does air with its relative dielectric constant ϵ of 1; however, by making the dielectric constant of the core rod greater than the dielectric constant of the sheath,
- 10 the majority of the energy is confined within the core rod, protecting these fields from outside influence. The dielectric constant of the core rod may be more than about two (2), three (3), five (5), seven (7), nine (9), ten (10), fifteen (15), twenty (20), or fifty (50) times higher than the dielectric constant of the sheath. Preferably, the difference between the dielectric constant of the core rod and the dielectric
- 15 constant is greater than about 10. This efficiently propagates the microwave energy through the rods in a manner similar, but not identical, to the concept used in optical fiber transmission lines.

- In accordance with the present invention, features of the dielectric rod antenna and coaxial dielectric transmission lines are combined to form a series of concentric
- 20 collinear apertures, each operating in the fundamental HE_{11} mode over greater than 2:1 frequency ratios in their respective frequency bands.

- Referring to Fig. 2, the present invention is depicted in simplified schematic form.
- 25 Antenna 20, which in the embodiment described below is configured for operation both at about 9.4 GHz in "low" frequency X-band and at about 94 GHz in "high" frequency W-Band, includes a core rod 22 of dielectric constant ϵ_3 which is inserted into an outer rod 24 which has a dielectric constant ϵ_2 . The antenna 20 is is

surrounded by medium 26 of dielectric constant ϵ_1 (usually air), forming two concentric dielectric transmission lines, which are respectively coupled to a high band waveguide transducer 27 and a low band waveguide transducer 28. Dielectric constant ϵ_3 is preferably greater than dielectric constant ϵ_2 , which is preferably greater than dielectric constant ϵ_1 . By tapering the combined structure of antenna 20 in a controlled manner, the transmission line formed by dielectric rod 24 (dielectric constant ϵ_2) will provide for radiating low band radiation 30 along the tapered surface of rod 24 into the medium 26 (dielectric constant ϵ_1). The second collinear transmission line is formed by embedding dielectric rod 22 (dielectric constant ϵ_3) within dielectric rod 24 (dielectric constant ϵ_2) and will provide for radiating high band radiation 32 when rod 22 is exposed to the medium 26 and is tapered into the medium 26 as depicted by Fig. 2. The dielectric constant ϵ_2 of the outer rod 24 is preferably in the range of about 1.5 to about 10, and more preferably about 2.08, as provided by Teflon™ material. To confine the majority of the energy in the core rod 22, the dielectric constant ϵ_3 of the core rod 22 is preferably in the range of about 10 to about 30, more preferably around 30 as provided by barium tetra-titanate.

The bandwidth and gain of each of these apertures can be individually adjusted for a specific application or they can be optimized for combined operation as feed antennas as part of a large active aperture phased array antenna system.

Referring collectively to Figs. 3 and 4a - 4c, there is depicted a first embodiment of the present invention. Antenna 40 includes support housing 42, which is made from two symmetrical mirror image aluminum housing blocks 44a, 44b, each having length 43 of about 8.9 cm (3.5 in.), width 45 of about 5.7 cm (2.25 in.) and combined height 47 of about 4.1 cm (1.625 in.). Block 44a clamps down on block

44b and is secured in place by screws 46a - 46d passing through clearance holes 48a - 48d coupling with threaded holes 50a - 50d. Support rod 52 includes tapered rod 54, thin tubing 56 and tapered transition 58. Tapered transition 58 at proximal end 59 of tapered rod 54 has about a 45° taper thereat and couples tapered rod 54 with thin tubing 56. Support rod 52 is made of a relatively loss-less dielectric material having a dielectric constant greater than that of air, e.g., having an $\epsilon_2 \approx 2.08$, such as that provided by thermoplastic resins and, in particular, the commonly known fluorocarbon resin Teflon (trademark). Thin tubing 56 can be formed from standard AWG20 teflon tubing. Tapered rod 54 has a straight section 60 having a diameter 62 of approximately 1.9 cm (0.75 in.) for tapered rod 54 support in cylindrical recess 64 of housing blocks 44a, 44b, and having a support length 66 of about 2.5 cm (1.0 in.). Thin tubing 56 is likewise supported in cylindrical recess 68 of housing blocks 44a, 44b, cylindrical recess 68 being dimensioned to allow a press-fit of AWG20 size tubing. Cylindrical recess 68 is in axial alignment with cylindrical recess 64. Tapered rod 54 tapers from dimension 62 at the edge of housing blocks 44a, 44b to dimension 70 of 2mm at tapered rod distal end 72 over taper length 74 of about 12.1 cm (4.75 in.).

Support rod 52 axially houses therein an axial cylindrical cavity 76 of approximately 1 mm diameter. Cylindrical cavity 76 is filled with powder-like high dielectric material 78 and has proximal end cap 80 and distal end cap 82 terminating each end. Proximal end cap 80 and distal end cap 82 are typically rigid pieces of approximately 1 mm diameter press-fit supported over a suitable length of cylindrical cavity 76, typically made of the same material as powder-like material 78, and act as plugs. Proximal end cap 80 has a taper 81 over length 84 of 2 mm and protrudes the same amount from housing blocks 44a, 44b. Distal end cap 82 has a similar taper 83 over length 86 of 2mm. Distal end cap 82 extends distance 88 of approximately about 2.86 cm (1.125 in.) from tapered rod distal end 72.

In the first embodiment, material with a dielectric constant of 30, such as barium tetra-titanate powder or nickel-aluminum titanate powder, as is described in U.S. Patent No. 4,800,350 entitled "Dielectric Waveguide Using Powdered Material", was found to be a most effective powder-like material 78. Those skilled in the art will
5 recognize that the material and the powder consistency can be varied to enable changeable antenna frequencies.

As referred to above, the low frequency antenna of the present embodiment is designed to operate at about 9.4 GHz while the high frequency antenna operates at
10 about 94 GHz. There are, accordingly, two corresponding waveguide ports for the respective frequency inputs, namely, low frequency port 90 and high frequency port 92. Low frequency port 90 is a standard WR90 waveguide port, having about a 2.3 cm by 1.0 cm (0.9 in. by 0.4 in.) waveguide mouth. High frequency port 92 is a standard WR8 waveguide port having about a 0.2 cm by 0.1 cm (0.08 in. by 0.04
15 in.) waveguide mouth. Standard mounting holes are provided to enable corresponding WR90 and WR8 feed transmission lines (not shown) to be coupled to support housing 42. In the first embodiment, low frequency port 90 is physically located at about 90° to high frequency port 92. High frequency port 92 is axially in line with the dielectric rods of the antenna. Low frequency port 90 tapers over
20 about 90° bend 94 to interface with end 96 of housing cylindrical recess 64. As such, low frequency port 90 tapers to end 96 having guide dimensions 98, 100 of 2.3 cm by 2.3 cm (0.9 in. by .9 in.) respectively.

Support rod 52 can be press fit into housing cylindrical recess 64. However,
25 support rod 52 can be allowed to be axially moveable to allow frequency tuning of the antenna if desired.

Those skilled in the art will appreciate that it is possible to extend this invention to operation in three frequency bands by triaxially embedding dielectric rods of

increasingly greater dielectric constants. This is schematically depicted in Fig. 5. Core rod 122 of dielectric constant ϵ_4 is inserted into rod 124 of dielectric constant ϵ_3 , which in turn is inserted into rod 125 of dielectric constant ϵ_2 . The non-imbedded portions of the respective rods are surrounded by medium 126 of dielectric constant ϵ_1 (usually air), forming three concentric dielectric transmission lines, which are respectively coupled to high band waveguide transducer 127, mid-band waveguide transducer 128 and low band waveguide transducer 130. To confine the majority of the high band energy in the core 122 until the core 122 is exposed to the medium 126 (dielectric constant ϵ_1) and radiates energy 136, the dielectric constant ϵ_4 is preferably greater than about 10 and also preferably greater than the dielectric constant ϵ_3 of rod 124. The value of ϵ_4 preferably ranges from about 20 to about 30, and is more preferably about 30, the value of barium tetra-titanate. To confine the majority of the mid band energy in the rod 124 until the rod 124 is exposed to the medium 126 (dielectric constant ϵ_1) and radiates energy 134, the dielectric constant ϵ_3 is preferably greater than about 10 and also preferably greater than the dielectric constant ϵ_2 of rod 125. The value of ϵ_3 preferably ranges from about 10 to about 20, and is more preferably about 12. Exemplary adequate materials for rod 124 include silicon ($\epsilon = 11.8$) and gallium arsenide ($\epsilon = 13.2$). The dielectric constant ϵ_2 of the first rod 125 radiating low band energy 132 when tapered into the medium 126 (dielectric constant ϵ_1) is preferably in the range of about 1.5 to about 10, more preferably about 2.08, as provided by Teflon™ material.

Those skilled in the art can also appreciate that it is possible to extend this invention to operation in four, five, six or any number of frequency bands by increasing the multiple embedding dielectric rods of increasingly greater dielectric constants.

Further, dielectric rod antennas with periodic perturbations excited by dielectric rod transmission lines have been developed for use over smaller bandwidths (a few percent) to shape the radiation patterns for omnidirectional coverage and are described in the literature. These configurations, examples of which are depicted in Figs. 6a, 6b, and 6c, could also be incorporated by those skilled in the art.

As has been described hereinabove, a coaxial dielectric rod antenna (CDRA) has been provided with multi-frequency collinear apertures that combines thin (relative to a half wavelength in air) dielectric rod antenna elements embedded with a series of one or more coaxial dielectric waveguides with collinear tapered radiating apertures of increasing dielectric constant, forming an array of two or more radiating apertures. Each of the radiating apertures on the CDRA can operate over a broad bandwidth in different frequency bands. All of the elements in the CDRA support both linear and circular polarizations and each of the collinear apertures can be coupled to separate electronics modules, each of which are optimized for use in the specific frequency band of operation.

When combined into a phased array antenna, the CDRA antenna elements can provide several novel features:

- 1) Each radiating aperture on the coaxial rod has an operating bandwidth ratio of at least 2:1. Thus, a two-aperture antenna would provide an operating bandwidth of about 4:1 and a three-aperture antenna would operate over an about 8:1 frequency range.
- 2) A multi-aperture CDRA could operate in widely separated frequency bands such as X-Band and W-Band.

- 3) The diameter of the CDRA dielectric waveguides can be very small at the lowest operating frequencies, enabling dense spacing to support operation at the highest operating frequencies.
- 5 4) The CDRA feed elements reduce the number and complexity of the electronics in the feed manifold by enabling separate, optimized electronics transmitter/receiver (T/R) circuits to be packaged in separate planes located behind the antenna surface.
- 10 5) The endfire nature of the CDRA eliminates the need for a metallic ground plane at the base of the feed antennas, which is required for most currently used broadband antenna feed elements. This will reduce the weight of phased array antennas and enable mounting antennas of this type on plastic and composite surfaces now in common use in aircraft, spacecraft and automotive
15 structures.

All of the numerical and quantitative measurements set forth in this application (including in the examples and in the claims) are approximations.

- 20 The invention illustratively disclosed or claimed herein suitably may be practiced in the absence of any element which is not specifically disclosed or claimed herein. Thus, the invention may comprise, consist of, or consist essentially of the elements disclosed or claimed herein.
- 25 The following claims are entitled to the broadest possible scope consistent with this application. The claims shall not necessarily be limited to the preferred embodiments or to the embodiments shown in the examples.

CLAIMS

1. A method of structuring an antenna, comprising the steps of:
 - 5 providing a first dielectric antenna rod having a first dielectric constant, the first dielectric antenna rod being coupled to a first frequency transmission source for propagating first frequency band radiation from the first dielectric antenna rod into a medium having a medium dielectric constant; and
 - 10 coaxially mounting the first dielectric antenna rod within a second dielectric antenna rod having a second dielectric constant, the second dielectric antenna rod being coupled to a second frequency transmission source for propagating second frequency band radiation from the second dielectric antenna rod into the medium;
 - 15 wherein the first dielectric constant is greater than the second dielectric constant and the second dielectric constant is greater than the medium dielectric constant, and wherein the difference between the first dielectric constant and the second dielectric constant is greater than about 10.
- 20 2. A method of structuring an antenna, comprising the steps of:
 - 25 providing a first dielectric antenna rod having a first dielectric constant, the first dielectric antenna rod being coupled to a first frequency transmission source for propagating first frequency band radiation from the first dielectric antenna rod into a medium having a medium dielectric constant;
 - coaxially mounting the first dielectric antenna rod within a second dielectric antenna rod having a second dielectric constant, the second dielectric antenna

rod being coupled to a second frequency transmission source for propagating second frequency band radiation from the second dielectric antenna rod into the medium; and

5 coaxially mounting the second dielectric antenna rod within a third dielectric antenna rod having a third dielectric constant, the third dielectric antenna rod being coupled to a third frequency transmission source for propagating third frequency band radiation from the third dielectric antenna rod into the medium;

10 wherein the first dielectric constant is greater than the second dielectric constant, the second dielectric constant is greater than the third dielectric constant, and the third dielectric constant is greater than the medium dielectric constant, and wherein the difference between the first dielectric constant and
15 the third dielectric constant is greater than about 10.

3. An antenna comprising:

20 a first dielectric antenna rod having a first dielectric constant, the first dielectric antenna rod being coupled to a first frequency transmission source for propagating first frequency band radiation from the first dielectric antenna rod into a medium having a medium dielectric constant; and

25 a second dielectric antenna rod having a second dielectric constant, the second dielectric antenna rod being coupled to a second frequency transmission source for propagating second frequency band radiation from the second dielectric antenna rod into the medium, the first dielectric antenna rod being coaxially mounted within the second dielectric antenna rod;

wherein the first dielectric constant is greater than the second dielectric constant and the second dielectric constant is greater than the medium dielectric constant, and wherein the difference between the first dielectric constant and the second dielectric constant is greater than about 10.

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4. An antenna comprising:

a first dielectric antenna rod having a first dielectric constant, the first dielectric antenna rod being coupled to a first frequency transmission source for propagating first frequency band radiation from the first dielectric antenna rod into a medium having a medium dielectric constant;

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a second dielectric antenna rod having a second dielectric constant, the second dielectric antenna rod being coupled to a second frequency transmission source for propagating second frequency band radiation from the second dielectric antenna rod into the medium, the first dielectric antenna rod being coaxially mounted within the second dielectric antenna rod; and

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a third dielectric antenna rod having a third dielectric constant, the third dielectric antenna rod being coupled to a third frequency transmission source for propagating third frequency band radiation from the third dielectric antenna rod into the medium, the second dielectric antenna rod being coaxially mounted within the third dielectric antenna rod;

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wherein the first dielectric constant is greater than the second dielectric constant the second dielectric constant is greater than the third dielectric constant, and the third dielectric constant is greater than the medium dielectric constant, and wherein the difference between the first dielectric constant and the third dielectric constant is greater than about 10.

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5. The method of claims 1 or 2 or the antenna of claims 3 or 4, wherein the first dielectric constant is within a range of about 10 to about 30.
- 5 6. The method or antenna of claim 5, wherein the first dielectric constant is about 30.
7. The method or antenna of claim 5, wherein the first dielectric antenna rod is essentially made of barium tetra-titanate.
- 10 8. The method of claim 1 or the antenna of claim 3, wherein the second dielectric constant is within a range of about 1.5 to about 10.
- 15 9. The method or antenna of claim 8, wherein the second dielectric constant is about 2.08.
10. The method or antenna of claim 8, wherein the second dielectric antenna rod is essentially made of teflon™ material.
- 20 11. The method of claim 1, wherein the first dielectric antenna rod is formed by:
- forming an axial cylindrical cavity along the length of the second dielectric antenna rod;
- 25 filling the axial cylindrical cavity with a dielectric powder having the first dielectric constant; and

securing the dielectric powder within the axial cylindrical cavity with end plugs having the first dielectric constant located at respective proximal and distal ends of the second dielectric antenna rod.

- 5 12. The method of claim 11, wherein the second dielectric antenna rod is essentially made of a thermoplastic resin and the dielectric powder is barium tetra-titanate or nickel-aluminum titanate.
- 10 13. The method of claim 11, wherein the thermoplastic resin is fluorocarbon resin teflon™ material.
- 15 14. The method of claim 1, wherein the first dielectric antenna rod is formed by:

forming an axial cylindrical cavity along the length of the second dielectric antenna rod;

filling the axial cylindrical cavity with a dielectric rod having the first dielectric constant; and
- 20 securing the dielectric rod within the axial cylindrical cavity with end plugs having the first dielectric constant located at respective proximal and distal ends of the second dielectric antenna rod.
- 25 15. The method of claim 14, wherein the second dielectric antenna rod is essentially made of a thermoplastic resin and the dielectric rod is essentially made of barium tetra-titanate or nickel-aluminum titanate.
16. The method of claim 15, wherein the thermoplastic resin is fluorocarbon resin teflon™ material.

17. The method of claim 1 or the antenna of claim 3, wherein:
- 5 the first frequency transmission source is axially coupled to the first dielectric antenna rod; and
- the second frequency transmission source is coupled to the second dielectric antenna by a transmission line axially offset from the second dielectric antenna rod.
- 10
18. The method of claim 1 or the antenna of claim 3, wherein each of the first dielectric antenna rod and the second dielectric antenna rod has an operating beamwidth ratio of at least 2:1, and thus the antenna has an operating beamwidth ratio of at least 4:1.
- 15
19. The method of claim 1 or the antenna of claim 3, wherein the first dielectric antenna rod operates in X-Band and the second dielectric antenna rod operates in W-Band.
- 20
20. The method or the antenna of claim 19, wherein the first dielectric antenna rod operates at about 9.4 GHz and the second dielectric antenna rod operates at about 94 GHz.
- 25 21. The method of claim 1 or the antenna of claim 3, wherein a portion of the first dielectric antenna rod is tapered, and wherein a portion of the second dielectric antenna rod is tapered.

22. The method of claim 2 or antenna of claim 4, wherein the first dielectric constant is greater than about 10.
23. The method or antenna of claim 22, wherein the first dielectric constant is within a range of about 20 to about 30.
24. The method or antenna of claim 23, wherein the first dielectric constant is about 30.
25. The method or antenna of claim 23, wherein the first dielectric antenna rod is essentially made of barium tetra-titanate.
26. The method of claim 2 or the antenna of claim 4, wherein the second dielectric constant is greater than about 10.
27. The method or the antenna of claim 26, wherein the second dielectric constant is within a range of about 10 to about 20.
28. The method or the antenna of claim 27, wherein the second dielectric constant is about 12.
29. The method or the antenna of claim 27, wherein the second dielectric antenna rod is made of silicon and has a second dielectric constant of about 11.8.
30. The method or the antenna of claim 27, wherein the second dielectric antenna rod is made of gallium arsenide and has a second dielectric constant of about 13.2.

31. The method of claim 2 or the antenna of claim 4, wherein the third dielectric constant is within a range of about 1.5 to about 10.
32. The method or the antenna of claim 31, wherein the third dielectric antenna rod is essentially made of teflon™ material and the third dielectric constant is about 2.08.
33. The method of claim 2 or the antenna of claim 4, wherein each of the first dielectric antenna rod, the second dielectric antenna rod and the third dielectric antenna rod has an operating beamwidth ratio of at least 2:1, and thus the antenna has an operating beamwidth ratio of at least 8:1.
34. The antenna of claim 3, wherein the second dielectric antenna rod includes an axial cylindrical cavity along the length of the second dielectric antenna rod, the axial cylindrical cavity being filled with a dielectric powder having the first dielectric constant, and the dielectric powder being secured within the axial cylindrical cavity by end plugs having the first dielectric constant and being located at respective proximal and distal ends of the second dielectric antenna rod.
35. The antenna of claim 34, wherein the second dielectric antenna rod is essentially made of a thermoplastic resin and the dielectric powder is barium tetratitanate or nickel-aluminum titanate.
36. An antenna for propagating a number N of electromagnetic waves into a medium, each electromagnetic wave having a frequency band associated therewith, the antenna comprising:

N dielectric antenna rods, each having a dielectric constant associated therewith, the N dielectric antenna rods including a core dielectric antenna rod, a number N-2 of intermediate antenna rods and an outer dielectric antenna rod; and

5

N electromagnetic energy transmission sources, each transmission source generating and propagating one of the N electromagnetic waves from one of the dielectric antenna rods into the medium, the medium having a medium dielectric constant;

10

wherein the core dielectric antenna rod is coaxially mounted within one of the N-2 intermediate antenna rods, each of the N-3 remaining intermediate antenna rods is coaxially mounted within another one of the remaining intermediate antenna rods, except for one of the remaining intermediate antenna rods which is coaxially mounted within the outer antenna rod; and

15

wherein, for a given dielectric antenna rod included in the antenna, the dielectric constant of the given dielectric antenna rod is greater than the dielectric constant of the dielectric antenna rod within which the given dielectric antenna rod is coaxially mounted, and the outer dielectric antenna rod has a dielectric constant greater than the medium dielectric constant.

20

37. A method of structuring an antenna, comprising the steps of:

25

providing a first dielectric antenna rod having a first dielectric constant; and

mounting the first dielectric antenna rod within a second dielectric antenna rod having a second dielectric constant;

wherein the first dielectric constant is greater than the second dielectric constant.

38. A method of structuring an antenna, comprising the steps of:

5

providing a first dielectric antenna rod having a first dielectric constant;

mounting the first dielectric antenna rod within a second dielectric antenna rod having a second dielectric constant; and

10

mounting the second dielectric antenna rod within a third dielectric antenna rod having a third dielectric constant;

15

wherein the first dielectric constant is greater than the second dielectric constant, and the second dielectric constant is greater than the third dielectric constant.

39. An antenna comprising:

20

a first dielectric antenna rod having a first dielectric constant; and

a second dielectric antenna rod having a second dielectric constant;

25

wherein the first dielectric constant is greater than the second dielectric constant.

40. An antenna comprising:

a first dielectric antenna rod having a first dielectric constant;

5 a second dielectric antenna rod having a second dielectric constant; and

a third dielectric antenna rod having a third dielectric constant;

10 wherein the first dielectric constant is greater than the second dielectric constant and the second dielectric constant is greater than the third dielectric constant.

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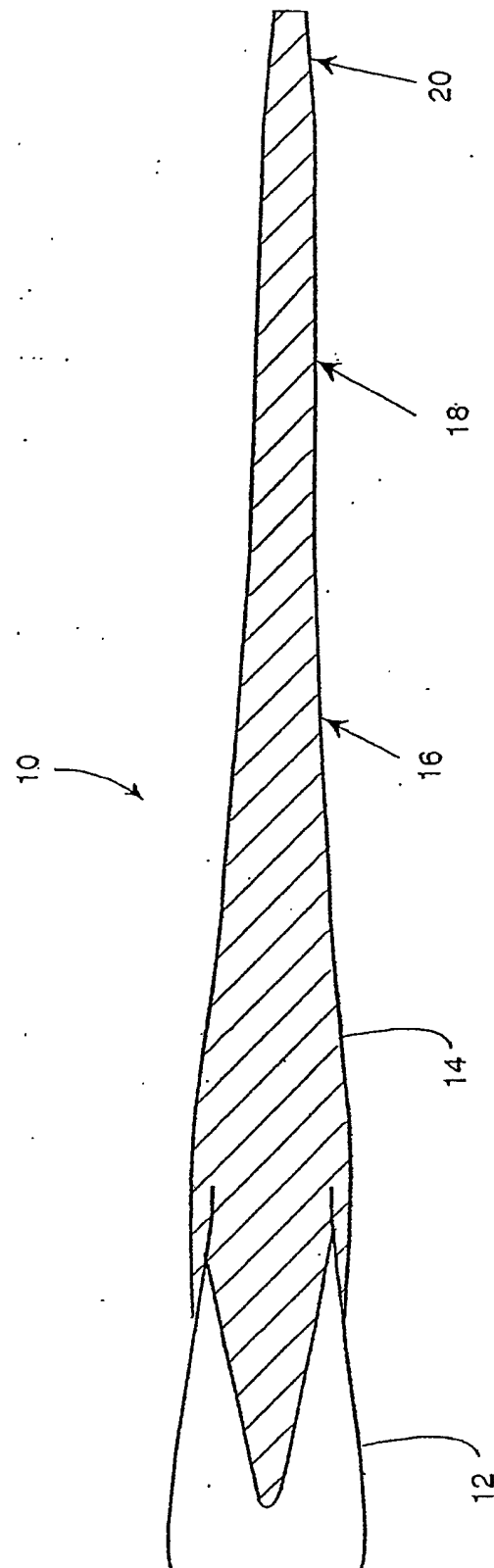


FIG. 1
(PRIOR ART)

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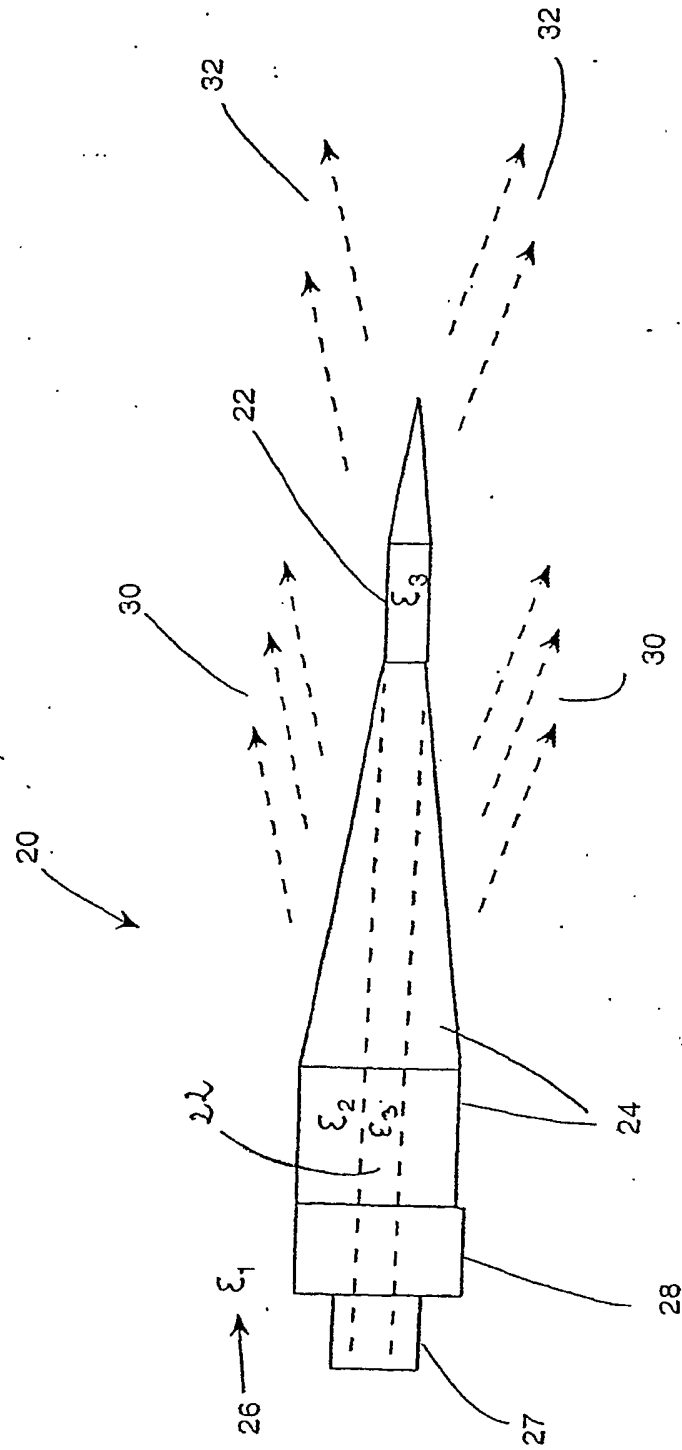


FIG. 2

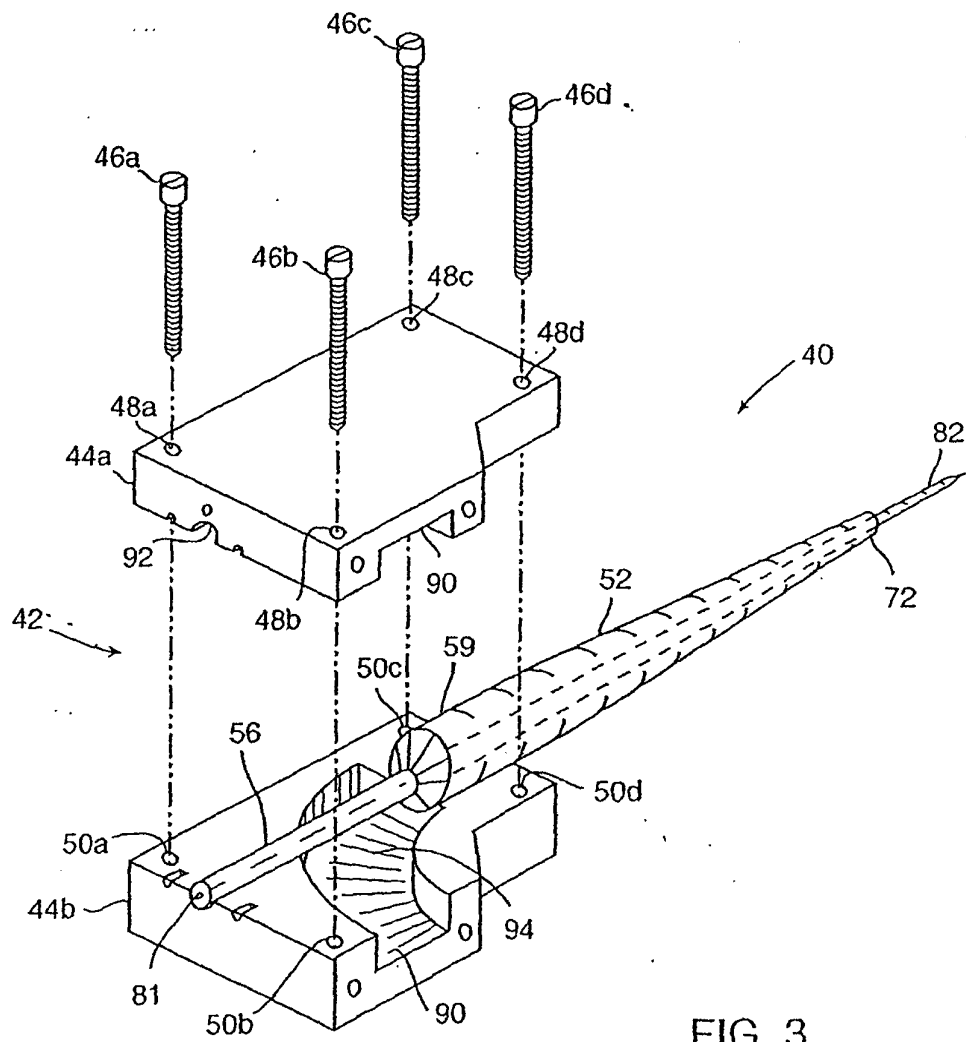
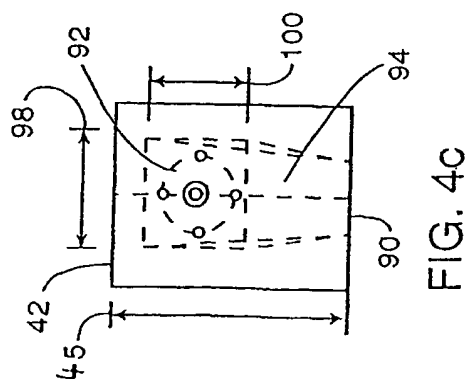
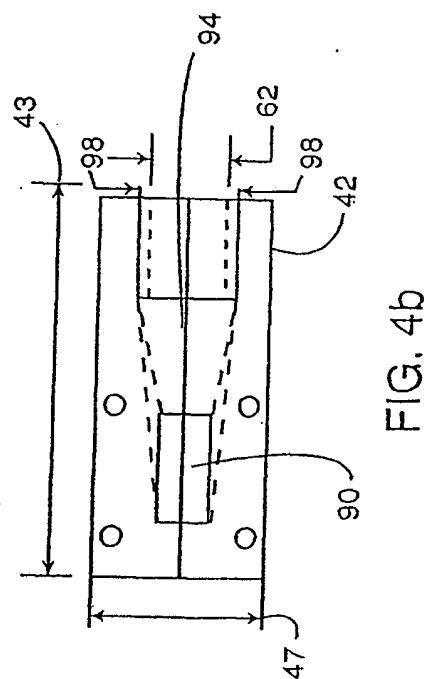
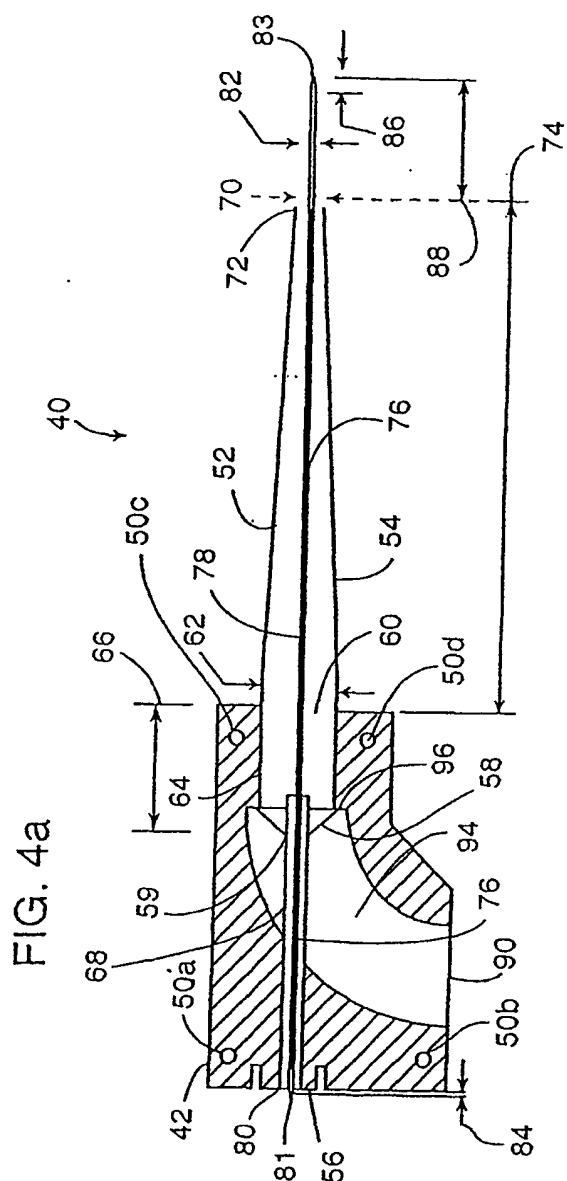


FIG. 3



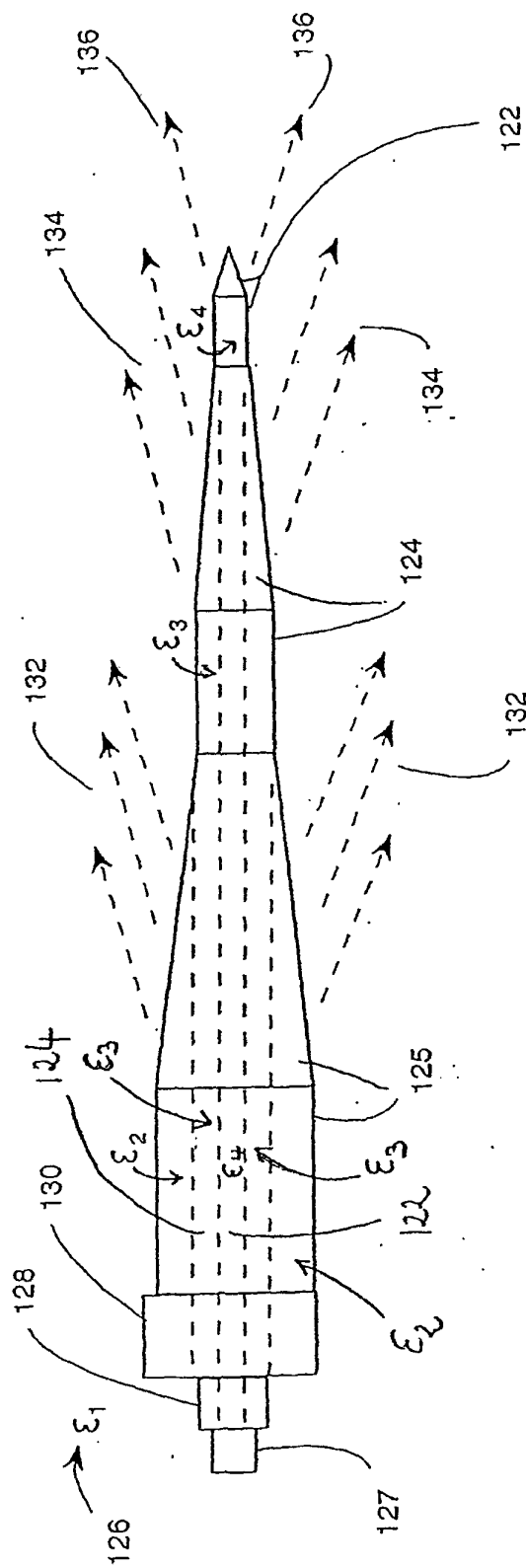


FIG. 5



FIG. 6a

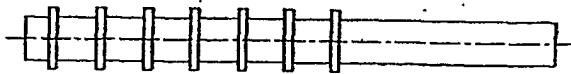


FIG. 6b



FIG. 6c

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/21903

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01Q13/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, COMPENDEX, INSPEC, IBM-TDB, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
E	WO 01 52354 A (BRIDGES WILLIAM B ;HRL LAB LLC (US); POPA ADRIAN E (US)) 19 July 2001 (2001-07-19) the whole document	1-40
A	US 4 274 097 A (KRALL ALBERT D ET AL) 16 June 1981 (1981-06-16) cited in the application column 6, line 39 -column 7, line 33 column 8, line 1 -column 8, line 29 column 9, line 30 -column 10, line 5 abstract; figures 7,7A,8 -/--	1,3,5-9, 11,12, 14,15, 17, 22-24, 27,28, 31,34, 35,37,39

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

29 April 2002

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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A	<p>US 5 684 495 A (DYOTT RICHARD B ET AL) 4 November 1997 (1997-11-04) cited in the application</p> <p>column 2, line 11 -column 2, line 49 column 4, line 63 -column 5, line 4 abstract; figures 1,2</p> <p>----</p>	<p>1-6,8,9, 17, 22-24, 27,28, 31,36-40</p>
A	<p>US 5 936 589 A (KAWAHATA KAZUNARI) 10 August 1999 (1999-08-10)</p> <p>column 3, line 44 -column 4, line 45 abstract; figures 1,2</p> <p>----</p>	<p>1,3,5,6, 8,9,17, 22-24, 27,28, 31,37,39</p>
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